

PREDICTION OF SPATIAL YIELD AND WATER USE IN AGRICULTURE AS A FUNCTION OF ENVIRONMENTAL CONDITIONS

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ABSTRACT

Water is one of the most limiting resources for agricultural production in Georgia. Due to the uneven distribution of rainfall, supplemental irrigation is often required to be able to produce a sustainable yield level. In addition farmers have to cope with different soil water holding characteristics which also affect yield and final production. As a result both the temporal variation of the weather conditions and the spatial variability of soil conditions affect both crop growth, development and yield. Computer-based decision support systems have been developed to help understand the interaction between crops and the environment. In this analysis crop simulation models for soybean, peanut, maize, and wheat were used to study the relation between water use, yield, climatic, and soil conditions. The crop models SOYGRO, PNUTGRO, CERES-Maize and CERES-Wheat were linked with the Geographic Information System PC-ARC/INFO. This system was used to simulate crop growth and development for each polygon or field with different soil characteristics and to predict yield and other related crop input and output variables. Results showed that both water use and yield varied significantly as a function of seasonal climatic variation and soil water holding characteristics.

INTRODUCTION

Crop simulation models and similar computer decision aids have been developed to help farmers with crop management and other related decision processes (Hoogenboom et al., 1987; IBSNAT, 1989). The crop models predict growth, development, and yield as a function of soil and climatic conditions and crop management. These models are normally site specific, i.e. they predict yield only for one particular site for which the physical and chemical description of the soil profile and the weather conditions are known. These models, however, are transferrable, in that they can predict growth and development for other sites if the required environmental variables are available (Hoogenboom

et al., 1991a). For many model applications it is assumed that environmental conditions are fixed with respect to spatial distribution, while in reality there is a spatial variation of the input conditions. With water becoming a limiting resource, it has become important to not only look at agricultural water use requirements on a single point basis, but also on an areal basis. Geographic information systems (GIS) are an ideal computer tool to handle spatial variable databases. The objective of this study was to expand the use of crop simulation models through linkage with GIS and spatial soil databases. The second objective was to apply this computer system to study distribution of yield, water use, and other agronomic variables as a function of soil spatial variability on a farm level.

METHODS

Computer Models

Computer models for drybean, peanut, soybean, wheat, and maize were selected, which include BEANGRO (Hoogenboom et al., 1991b), SOYGRO (Jones et al., 1989), PNUTGRO (Boote et al., 1989), CERES-Maize (Ritchie et al., 1989), and CERES-Wheat (Godwin et al., 1989.). This suite of simulation models belongs to the IBSNAT (International Benchmark Sites Network for Agrotechnology

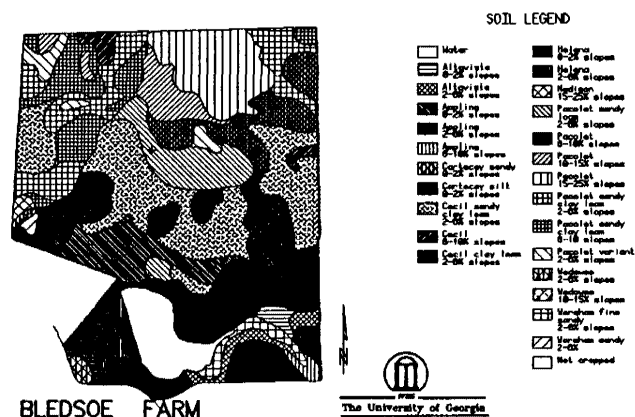


Figure 1. Soil Map of the Bledsoe Research Farm of the Georgia Experiment Station.

Transfer) family of models which have been integrated into a Decision Support System for Agrotechnology Transfer (DSSAT; IBSNAT, 1989). These crop models use identical input/output file structures (IBSNAT, 1990) and have similar soil water and nitrogen balances, which facilitates the linkage to common data bases. The GIS selected for this study was PC ARC/INFO (ESRI, 1988), based on experience from a previous study (Lal et al., 1992).

Databases

The soil characteristics of the Bledsoe research farm of the Georgia Experiment Station were described in detail by Perkins et al. (1985). The Bledsoe farm consists of 82.6 ha (204 acres) and is located at a latitude of 33° 10' N and longitude 84° 45' W near Williamson in Pike County, Georgia. Elevation ranges from 262 to 274 m, with an average elevation of 267 m (875 ft). A total of nine soil series were found, of which the six major ones have been described in detail. The soil map of Perkins et al. (1985) was digitized and processed in PC ARC/INFO (Fig. 1). The Appling series is the most dominant soil, followed by the Pacolet and Cecil series. Slopes vary from 0 to 15 %. Each polygon was identified with a unique identifier, which was referenced to the soil physical characteristics of that particular profile. Weather data were obtained from an automated weather station installed at the Bledsoe research farm.

Geographic Information System

An user-friendly interface was developed in PC ARC/INFO to allow the user to select various options within

Table 1. Yield, Yield Components and Other Variables which Can Be Displayed on a Spatial Basis.

Variables	Unit
Seed Yield	t/ha
Pod Yield	t/ha
Total Biomass	t/ha
Cumulative Evapotranspiration	mm
Cumulative Rainfall	mm
Cumulative Irrigation	mm
Number of Irrigation Events	#
Total Nitrogen Uptake	kg/ha
Nitrogen Leached	kg/ha
Planting to Flowering Duration	Days
Planting to Physiological Maturity Duration	Days
Drought Stress-Vegetative Development	(Relative)
Drought Stress-Reproductive Development	(Relative)
Nitrogen Stress-Vegetative Development	(Relative)
Nitrogen Stress-Reproductive Development	(Relative)

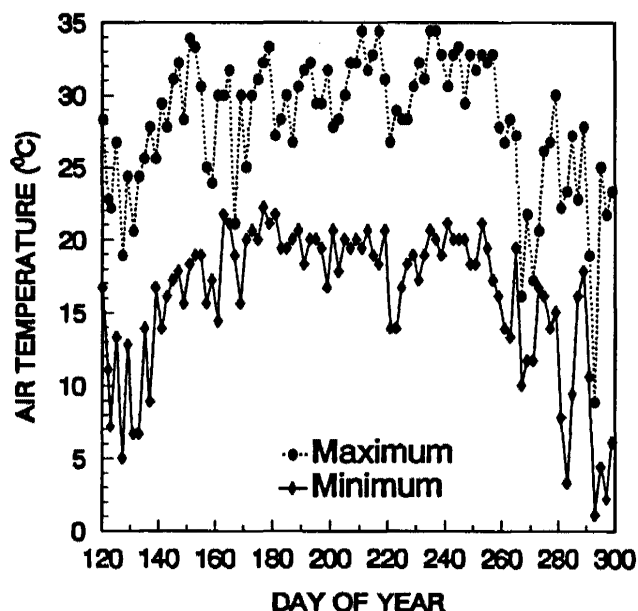


Figure 2. Daily Maximum and Minimum Air Temperature Recorded during the 1989 Growing Season at the Bledsoe Research Farm.

the system. After selecting a map the user can delineate a partial or full coverage of the soils map for further processing by the GIS system. The user then selects a crop, either dry bean, maize, peanut, soybean, or wheat, and a crop management strategy. This includes a cultivar selection, planting date, plant spacing and density, and irrigation management strategy. For the cereal crops a nitrogen fertilizer application strategy can also be selected. The polygon identifiers of the selected coverage and the characteristics of the management strategy are exported to ASCII text files. This information is linked with the spatial data base and the crop model is executed for each individual selected polygon. Following the crop models simulations, a

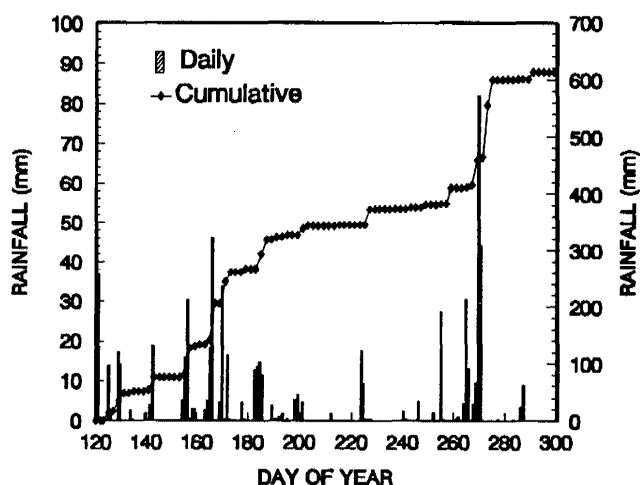


Figure 3. Daily Total Precipitation Recorded during the 1989 Growing Season at the Bledsoe Research Farm.

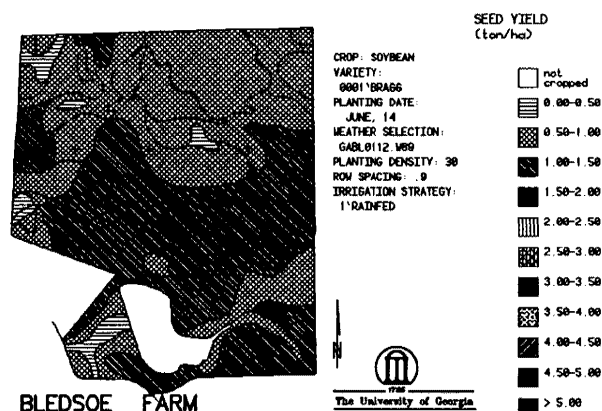


Figure 4. Predicted Spatial Variability of Soybean Yield for a Rainfed Crop, Planted on June 14, 1989.

summary of the results is imported into PC ARC/INFO. A list of the variables for which the spatial distribution can be displayed is presented in Table 1.

RESULTS

The developed GIS system can run an unlimited number of crop management simulations based on the selections by the user. As an example a soybean crop was simulated, using 1989 historical weather data. The cultivar selected was "Bragg," planted on June 14; planting density was 30 plants/m² and row spacing was 0.9 m. To study the effect of water management on yield, both a rainfed crop and an irrigated crop were simulated. For the irrigated management strategy an automatic irrigation routine was used, in which the crop was irrigated when the soil water content in the top 0.30 m of the profile dropped below 70 % of plant extractable soil water. It was assumed that nitrogen or any other plant nutrients were none-limiting and that the plants were not affected by any pest, disease or weed stresses. It was also assumed that for each polygon, corresponding to a

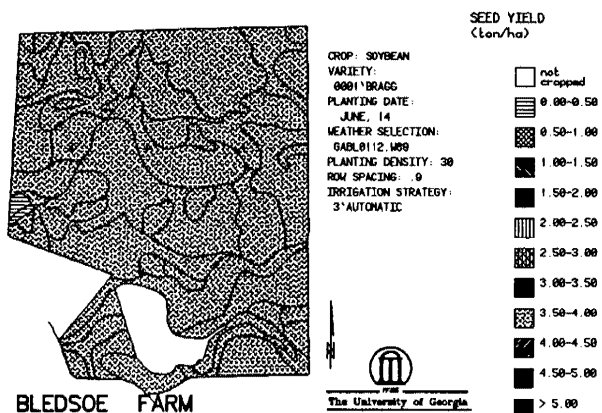


Figure 5. Predicted Spatial Variability of Soybean Yield for an Irrigated Crop, Planted on June 14, 1989.

particular soil type and slope, soil physical conditions were identical within this polygon.

The daily maximum and minimum air temperature for the growing season are presented in Fig. 2. On several days maximum temperatures were recorded as high as 35 °C. Daily and cumulative rainfall is presented in Fig. 3. July and August (Day 185 - Day 255) were relatively dry months. Heavy rainfall did not occur until day 270. As a result 1989 had a relatively dry summer growing season, with a low yielding potential for rainfed crops.

Yield distribution of the rainfed soybean crop varied between 0.0 and 2.0 t/ha (Fig. 4). The lowest yields were found on the Pacolet series, which has a relatively low water holding capacity; the highest yields were found on the Altavista series. For Appling, the most dominant soil series, yield varied between 1.0 and 1.5 t/ha. When irrigation was applied to create a non-stress soil environment, yield increased significantly and reached a level between 3.5 and 4.0 t/ha, independent of the spatial variation of the soil water holding characteristics (Fig. 5). However, total irrigation applied varied between 200 and 275 mm and was a function of soil characteristics (Fig. 6). Similarly total number of irrigations varied between 15 and 25 for the entire growing season and was also a function of soil physical characteristics.

DISCUSSION AND CONCLUSIONS

The graphical interface displays yield levels and other related variables as a function of soil conditions for each selected polygon. Currently the system does not integrate the predicted variables to give an absolute total yield or water use prediction for the area delineated by the user. The results from this study indicate that final yield can have a spatial distribution as a function of both the spatial variation of soil physical characteristics in a particular field and the crop management conditions selected by a user. Soybean yield for a rainfed crop, grown during the 1989 growing season, showed a strong spatial variation. No spatial variation in final soybean yield was found when irrigation was applied for the same growing season. However, there was a difference in both the total amount of irrigation and number of irrigations required to reach these yield levels as a function of soil physical conditions.

In addition there was a very strong interaction with weather conditions. Predicted yield showed less spatial variation as a function of soil physical conditions when the 1990 historical weather data were used as input, due to the larger number of rainfall events during the 1990 growing season, compared to the 1989 growing season (results are not presented in this paper). It can be concluded that the linkage between spatial data bases, crop simulation models and GIS can be an ideal computer tool to study spatial distribution of crop yield, water use, and other agronomic variables.

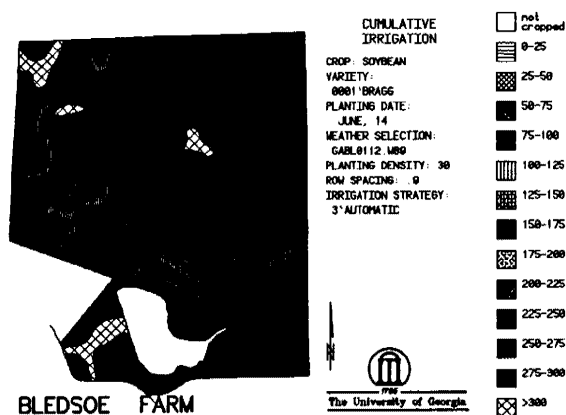


Figure 6. Predicted Spatial Variability of Total Seasonal Irrigation for an Irrigated Soybean Crop, Planted on June 14, 1989.

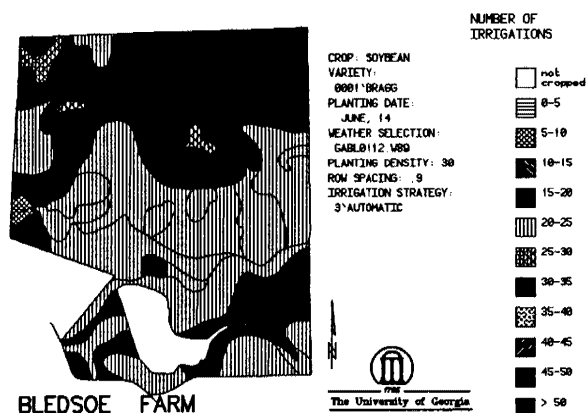


Figure 7. Spatial Variability of Predicted Number of Irrigations for an Irrigated Soybean Crop, Planted on June 14, 1989.

SOFTWARE AVAILABILITY

The individual crop simulation models used in this study are available from the authors of this paper upon request. The GIS system and linkage programs are currently still being expanded and tested and will be made available at a later date.

ACKNOWLEDGMENTS

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